

INFNNA-IV-2001/12
 DSFNA-IV-2001/12
 hep-ph/0105078
 May 2001

The diquark model: New Physics effects for charm and kaon decays *

Giancarlo D'Ambrosio[†] and Dao-Neng Gao[‡]

*Istituto Nazionale di Fisica Nucleare, Sezione di Napoli, Dipartimento di Scienze Fisiche,
 Università di Napoli I-80126 Napoli, Italy*

Abstract

Motivated by diquark exchange, we construct a class of extensions of the standard model. These models can generate large CP conserving and CP violating contributions to the doubly Cabibbo suppressed decays $D^0 \rightarrow K^+\pi^-$ without affecting $D^0 - \bar{D}^0$ mixing, contrary to what is usually believed in the literature. We find an interesting specific realization of these models, which has the LR chiral structure and can induce novel density \times density operators. It is new for non-leptonic kaon decays, and particularly, may provide a possible solution to the $\Delta I = 1/2$ rule and direct CP violation, without inducing large flavour changing neutral currents.

[†] E-mail: giancarlo.dambrosio@na.infn.it

[‡] E-mail: gao@na.infn.it, and on leave from *the Department of Astronomy and Applied Physics, University of Science and Technology of China, Hefei, Anhui 230026 China.*

* Work supported in part by TMR, EC-Contract No. ERBFMRX-CT980169 (EURODAΦNE).

1 Introduction

$D^0 - \overline{D}^0$ mixing and in general the charm sector is a very interesting place to test the Standard Model (SM) and its possible extensions [1, 2, 3, 4]. Recent data from FOCUS [5] and CLEO [6] have given further excitement to this field. Indeed the decay $D^0 \rightarrow K^+\pi^-$ has been now clearly observed; this may occur either through the double Cabibbo suppressed decays (DCS) or $D^0 - \overline{D}^0$ mixing with a subsequent Cabibbo favoured decays (CF). Data [5, 6] seem to exceed the naive SM expectation for the ratio of DCS to CF branching fractions is

$$R_D \equiv \left| \frac{A(D^0 \rightarrow K^+\pi^-)_{\text{DCS}}}{A(\overline{D}^0 \rightarrow K^+\pi^-)_{\text{CF}}} \right|^2 \quad (1)$$

$\approx \tan^4 \theta_C \approx 0.25\%$. Also SM predictions for $D^0 - \overline{D}^0$ mixing give a very negligible contribution.

It is generally believed that extensions of the SM can significantly affect the mixing but not the decay [4]. We challenge this statement by constructing a class of models which can generate large CP conserving and violating contributions only to DCS decays without affecting $D^0 - \overline{D}^0$ mixing. Thus we want to stimulate the experiments to also put bounds on CP violating contributions to DCS decays. These models are obtained by introducing a new scalar particle, a diquark χ , triplet under colour and can also be theoretically motivated in extensions of the SM. We fix the χ -coupling so that this is relevant for DCS decays i.e.

$$A(D^0 \rightarrow K^+\pi^-)_\chi \approx 10^{-2} G_F. \quad (2)$$

On the other hand, we also show that a possible large direct CP asymmetry in D^\pm channel could be induced by the diquark exchange.

Further we study more in detail an intriguing specific realization of these models which may have relevant implications for non-leptonic kaon decays [7], in particular the $\Delta I = 1/2$ rule. In fact, diquark interchange may generate non-leptonic $\Delta I = 1/2$ transitions, and the size of these contributions is appropriately constrained by $\Delta S = 2$ interactions. Thus one would have expected that a sizable interaction like the one in (2) for kaon decays, though in principle interesting for the $\Delta I = 1/2$ rule would generate a disaster in the flavour changing neutral current (FCNC) sector. However we do find, we think, an elegant solution to this problem, and it may also have other applications, for instance, generating new direct CP violating $\Delta S = 1$ operators without inducing large ε .

Differently from Ref. [8] our model is based on supersymmetry and we do not address the issue of strong CP problem.

2 Charm phenomenology

Mass and width eigenstates of the neutral D - system are written as linear combinations of the interactions eigenstates:

$$|D_{1,2}\rangle = p |D^0\rangle \pm q |\overline{D}^0\rangle \quad (3)$$

with eigenvalues $m_{1,2}$ and $\Gamma_{1,2}$. The mass and width average and difference are defined as

$$m = \frac{m_1 + m_2}{2}, \quad \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}, \quad (4)$$

$$x = \frac{m_2 - m_1}{\Gamma}, \quad y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}. \quad (5)$$

Decay amplitudes into a final state f are defined by

$$A_f \equiv \langle f | H_W | D^0 \rangle, \quad \overline{A}_f \equiv \langle f | H_W | \overline{D}^0 \rangle. \quad (6)$$

Then one can generally define the complex parameter:

$$\lambda_f \equiv \frac{q \overline{A}_f}{p A_f}. \quad (7)$$

The phenomenological evidence of possible large DCS decays comes from the analysis of CLEO [6] and FOCUS [5] that have been able to disentangle in the total data sample the DCS contribution from the $D^0 \rightarrow \overline{D}^0 \rightarrow K^+ \pi^-$ contribution. CLEO is able to study the time dependence in the ratio of the DCS to the CF decays, which in the limit of CP conservation is written as:

$$R(t) \equiv \left| \frac{\langle K^+ \pi^- | H_W | D^0(t) \rangle}{\langle K^+ \pi^- | H_W | \overline{D}^0(t) \rangle} \right|^2 = [R_D + \sqrt{R_D} y' \Gamma t + (y'^2 + x'^2) (\Gamma t)^2 / 4] e^{-\Gamma t}, \quad (8)$$

where R_D is defined in (1) and the final state interaction will generate a strong phase difference δ between the DCS and the CF amplitudes so that the following rotation is used in (8)

$$\begin{aligned} x' &= x \cos \delta + y \sin \delta, \\ y' &= y \cos \delta - x \sin \delta. \end{aligned}$$

CLEO by a careful time dependent study finds $R_D = (0.33_{-0.065}^{+0.063} \pm 0.040) \cdot 10^{-2}$ [6] with no-mixing fit, while FOCUS [5] assuming that there is no charm mixing and no CP violation finds $R_D = (0.404 \pm 0.085 \pm 0.025) \cdot 10^{-2}$. Possible CP violation effects in the mixing, the direct decay, and the interference between those two processes, characterized by A_M , A_D ,

and ϕ respectively, can affect the three terms in (8), where, to leading order, both x' and y' are scaled by $(1 \pm A_M)^{1/2}$, $R_D \rightarrow R_D(1 \pm A_D)$, and $\delta \rightarrow \delta \pm \phi$, as has been taken into account in the analysis by CLEO [6]. The corresponding values obtained in [6] are as follows:

$$A_M = 0.23_{-0.80}^{+0.63}, \quad A_D = -0.01 \pm 0.17, \quad \sin \phi = 0.00 \pm 0.60. \quad (9)$$

The SM prediction to the $D^0 - \overline{D}^0$ mixing is highly suppressed because it is the second order in α_W and has a very strong GIM suppression factor $m_s^4/(M_W m_c)^2$. The experimental data are

$$x \leq 0.03 \quad [2], \quad (10)$$

$$y' \cos \phi = (-2.5_{-1.6}^{+1.4}) \cdot 10^{-2} \quad [6], \quad (11)$$

and

$$y = (3.42 \pm 1.39 \pm 0.74) \cdot 10^{-2} \quad [5], \quad (12)$$

which cannot be clearly explained in the SM, where one expects [1]

$$x_{\text{SM}}, y_{\text{SM}} \leq 10^{-3}. \quad (13)$$

Theoretically, the strong phase δ was expected small, even vanishing in the SU(3) limit [9]. However, as pointed out in [3]: (i) a large δ would make the possible different signs of the measured $D^0 - \overline{D}^0$ mixing parameters shown in eqs. (11) and (12) consistent with each other, and (ii) recent data allow large values of δ . A large δ would be welcome in searching for direct CP asymmetry of $D^\pm \rightarrow K_S \pi^\pm$.

At the present, on one hand, the experimental results in charm phenomenology obviously need to be further improved; on the other hand, the discrepancy between the SM estimates and the data invites for speculations about the New Physics contributions.

3 Theory

As mentioned in the Introduction, let us now imagine the theory with the spin 0 diquark χ with the quantum numbers as follows [10, 11, 8], i.e.

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	B
χ	$\mathbf{3}$	1	$-1/3$	$-2/3$
χ^c	$\overline{\mathbf{3}}$	1	$1/3$	$2/3$

coupled to quark left-handed doublets, Q and right-handed singlets U, D and assume now that these are supersymmetric degrees of freedom. We write the R-parity conserving interaction in the superpotential W [10, 11]

$$W_{\text{diquark}} = g_L (h_L)_{ij}^A Q^i Q^j \chi_A + g_R (h_R)_{ij}^A U_i^c D_j^c \chi_A^c, \quad (14)$$

where i, j , and A are family indices, and the possible intergenerational mixing in $(h_L)_{ij}^A$ and $(h_R)_{ij}^A$ is assumed. h_L^A are flavour symmetric matrices in the weak-isospin basis, but they depart from symmetry in mass-eigenstate basis. Also (super-)Yukawa couplings of quarks to the two Higgses belong to this so-called superpotential. All this does make sense in the supersymmetric version of E_6 [12], therefore the terms in the superpotential are protected by the no-renormalization theorem [13]. Anyway, the supersymmetric predictions, for our purpose, can be regarded as the effective predictions of extensions of the SM satisfying the phenomenological limits including LEP data. This is different from Ref. [8] which is in the framework of a standard renormalizable theory.

From eq. (14), one can get the four-quark operators which have LL and RR chiral structures mediated by the diquarks χ and χ^c respectively. Interestingly, $\chi - \chi^c$ mixing [10] will generate instead the LR chiral structure. Generally, squaring $\Delta S = 1$ operators [7] could automatically lead to dangerous FCNC transitions. However, this is not the case for $\Delta C = 1$ operators contributing to DCS $D \rightarrow K\pi$ decays. Therefore, as shown in the next section, all the chiral structures LL , RR , and LR can enhance the DCS decays without affecting $D^0 - \bar{D}^0$ mixing, while only using the LR structure, one can get the possible large contributions to $\Delta I = 1/2$ transitions and new direct CP violation without large FCNC in kaon sector.

As further motivation, Voloshin recently [14] has considered a new centiweak four-quark interaction, with the strength $10^{-2}G_F$ to reproduce the experimental ratio of $\tau(\Lambda_b)/\tau(B_d)$. The new interaction arises through a weak $SU(2)$ singlet scalar field with quantum numbers of diquark χ :

$$b_R u_R \rightarrow \chi \rightarrow c_L d_L, \quad (15)$$

and the chiral structure is like the LR one of this paper.

4 Phenomenological analysis

4.1 DCS $D \rightarrow K\pi$ decays and $D^0 - \bar{D}^0$ mixing

It is straightforward to get the following chiral structures which could contribute to the DCS decays $D \rightarrow K\pi$:

$$\mathcal{L}^{LL} = \frac{g_L^2}{2m_\chi^2} (h_{11}^{L*} h_{22}^L) \left[(\bar{u}_L \gamma_\mu c_L) (\bar{d}_L \gamma^\mu s_L) - (\bar{u}_L \gamma_\mu s_L) (\bar{d}_L \gamma^\mu c_L) \right] + h.c., \quad (16)$$

$$\mathcal{L}^{RR} = \frac{g_R^2}{2m_\chi^2} (h_{11}^{R*} h_{22}^R) \left[(\bar{u}_R \gamma_\mu c_R) (\bar{d}_R \gamma^\mu s_R) - (\bar{u}_R \gamma_\mu s_R) (\bar{d}_R \gamma^\mu c_R) \right] + h.c., \quad (17)$$

and

$$\mathcal{L}^{LR} = \frac{g_L g_R}{2m_\chi^2} (h_{11}^{R*} h_{22}^L) \left\{ \left[(\bar{u}_R c_L) (\bar{d}_R s_L) - (\bar{u}_R s_L) (\bar{d}_R c_L) \right] \right.$$

$$+\frac{1}{4}\left[(\overline{u}_R\sigma^{\mu\nu}c_L)(\overline{d}_R\sigma_{\mu\nu}s_L)-(\overline{u}_R\sigma^{\mu\nu}s_L)(\overline{d}_R\sigma_{\mu\nu}c_L)\right]\Big\}+h.c. \quad (18)$$

Note that the LR structure (18) is derived by assuming the mixing between χ and χ^c , and we neglect the tensor contributions in the present work. Typically we can choose

$$\frac{g_L^2}{m_\chi^2} = \frac{g_R^2}{m_\chi^2} = \frac{g_L g_R}{m_\chi^2} \sim 10^{-6} \text{ GeV}^{-2} \quad (19)$$

for $m_\chi = 300 \text{ GeV}$, and $g_L = g_R = 0.3$. Thus, we can fix $h_{11}^{L*}h_{22}^L$, $h_{11}^{R*}h_{22}^R$, and $h_{11}^{R*}h_{22}^L$ to render that the diquark contributions to the DCS decays $D^0 \rightarrow K^+\pi^-$ from eqs. (16), (17), and (18) separately satisfy

$$A(D^0 \rightarrow K^+\pi^-)_\chi = G_\chi \approx 10^{-2} G_F, \quad (20)$$

which can compete with the corresponding SM contribution.

Note that all the couplings in eqs. (16), (17), and (18) do not induce $\Delta C = 2$ transitions, therefore, in the diquark models, one can get the enhancement of DCS decays $D^0 \rightarrow K^+\pi^-$ without the large $D^0 - \overline{D}^0$ mixing. Since $D^0 - \overline{D}^0$ mixing will involve other matrix elements of h_L and h_R than $h_{11}^{L,R}$ and $h_{22}^{L,R}$, we can tune these new couplings to accommodate the experimental bounds of this mixing.

The new $\Delta C = 1$ dynamics induced from the structures in eqs. (16)-(18) can contribute to the direct CP violation in DCS $D^0 \rightarrow K^+\pi^-$, which is

$$A_D^\chi \sim \Im m(h_{11}^{A*}h_{22}^B) \sin \delta, \quad (21)$$

where $A = B = L$ denotes the contribution from eq. (16), $A = B = R$ from eq. (17), and $A = R$ and $B = L$ from eq. (18) respectively. From experimental value in eq. (9), $A_D = -0.01 \pm 0.17$, we can get

$$|\Im m(h_{11}^{A*}h_{22}^B) \sin \delta| < 0.2. \quad (22)$$

The charge asymmetry in $D^\pm \rightarrow K_S \pi^\pm$ arises from the interference between the CF $D^\pm \rightarrow \overline{K}^0 \pi^\pm$ and DCS $D^\pm \rightarrow K^0 \pi^\pm$ decays, and the $K^0 - \overline{K}^0$ mixing will give the following contribution without any theoretical uncertainty [2, 15]:

$$\frac{\Gamma(D^+ \rightarrow K_S \pi^+) - \Gamma(D^- \rightarrow K_S \pi^-)}{\Gamma(D^+ \rightarrow K_S \pi^+) + \Gamma(D^- \rightarrow K_S \pi^-)} = -2\text{Re } \varepsilon_K \simeq -3.3 \cdot 10^{-3}. \quad (23)$$

Here the same asymmetry both in magnitude and in sign as eq.(23) will arise for the final state with a K_L instead of a K_S . On the other hand, from eqs. (16)-(18), one can get contribution to the asymmetry from the diquark exchange as

$$\frac{\delta\Gamma_\chi}{2\Gamma} = \frac{|\Gamma(D^+ \rightarrow K_S \pi^+) - \Gamma(D^- \rightarrow K_S \pi^-)|_\chi}{\Gamma(D^+ \rightarrow K_S \pi^+) + \Gamma(D^- \rightarrow K_S \pi^-)} \sim |\Im m(h_{11}^{A*}h_{22}^B) \sin \delta| \cdot 10^{-1}. \quad (24)$$

The factor 10^{-1} is due to the ratio of $\frac{g_A g_B}{m_\chi^2}$ and G_F . Thus using eq. (22), one can get

$$\frac{\delta\Gamma_\chi}{2\Gamma} \leq 10^{-2}. \quad (25)$$

Here eqs. (16)–(18) will make a contribution of the opposite sign to the asymmetry in $D^+ \rightarrow K_L \pi^+$ vs. $D^- \rightarrow K_L \pi^-$, which is different from the case of eq. (23). Note that this upper bound is one order larger than the value given in (23), which is consistent with the statement in Ref. [15]. Therefore, it is of interest to carry out the precise measurement of this asymmetry in order to exploit New Physics effects.

It is found that all three chiral structures LL , RR , and LR [(16)–(18)] can separately produce the large contributions to DCS $D^0 \rightarrow K^+ \pi^-$ decays without affecting $D^0 - \bar{D}^0$ mixing. This is somewhat contrary to the statement in Ref. [4]. In the kaon physics, only LR chiral structure is useful when we consider the constraints from the $K^0 - \bar{K}^0$ mixing.

4.2 $K^0 - \bar{K}^0$ mixing, $\Delta I = 1/2$ rule, and direct CP violation

Diquark exchange between the LR structure generates

$$\begin{aligned} \mathcal{L}^{LR} = & \frac{g_L g_R}{2m_\chi^2} \left\{ (h_{11}^{R*} h_{12}^L) \left[(\bar{u}_R u_L)(\bar{d}_R s_L) - (\bar{u}_R s_L)(\bar{d}_R u_L) \right] \right. \\ & \left. + (h_{12}^R h_{11}^{L*}) \left[(\bar{u}_L u_R)(\bar{d}_L s_R) - (\bar{u}_L s_R)(\bar{d}_L u_R) \right] \right\} + h.c. \end{aligned} \quad (26)$$

The matrix elements of these operators can be enhanced compared to the usual Q_- operator [7], and they will induce pure $\Delta I = 1/2$ transitions. Therefore, if $h_{ij}^{L(R)}$'s appearing in eq. (26) are not very small, one can expect a possible solution to the $\Delta I = 1/2$ rule.

However, we have to show that this structure could avoid large FCNC. Indeed $K^0 - \bar{K}^0$ mixing can be generated from $(\bar{d}_R s_L)^2$, $\bar{d}_R s_L \bar{d}_L s_R$, and $\bar{d}_L \gamma^\mu s_L \bar{d}_L \gamma_\mu s_L$. The last one is generated by the usual Q_- operator. If we assume that only one of the terms in (26), for instance $h_{11}^{R*} h_{12}^L$, is large and the other is very small then squaring the structure in (26) will **not** generate $K^0 - \bar{K}^0$ mixing because

$$\langle \bar{u}_R u_L \bar{u}_R u_L \rangle = 0.$$

Also, if we assume some electroweak phases in the $\Delta S = 1$ transitions induced by the diquark, we can obtain the contribution to ε'_χ . The only thing we have to be concerned that we do not generate too much ε_χ , i.e. $H_{\Delta S=2, CP}^\chi$ larger than the one in SM. Indeed in the SM

$$\Re(\varepsilon) \sim \frac{\Im m \langle \bar{K} | H_{\Delta S=2} | K \rangle}{\Re \langle \bar{K} | H_{\Delta S=2} | K \rangle} \sim 2 \cdot 10^{-3}.$$

The diquark exchange can generate $\Im m(A_0)$ in

$$\varepsilon' = i \frac{e^{i(\delta_2 - \delta_0)}}{\sqrt{2}} \omega \left[\frac{\Im m(A_2)}{\Re e(A_2)} - \frac{\Im m(A_0)}{\Re e(A_0)} \right],$$

to match the experimental result $\frac{\varepsilon'}{\omega} \sim 10^{-4}$ [2, 7] with a value for the imaginary part

$$\Im m(h_{12}^L h_{11}^{R*}) \sim 10^{-3}. \quad (27)$$

Now since we claim that with a particular choice of h^R and h^L ,

$$\Re e \langle \overline{K} | H_{\Delta S=2}^\chi | K \rangle < \Re e \langle \overline{K} | H_{\Delta S=2}^{SM} | K \rangle$$

then with the value in (27) we obtain

$$\frac{\Im m \langle \overline{K} | H_{\Delta S=2} | K \rangle}{\Re e \langle \overline{K} | H_{\Delta S=2} | K \rangle} < 10^{-3}$$

and so there is no problem for $\Re e(\varepsilon)$. If the electroweak phase is only in h_{12}^L , the induced electric dipole moment of the neutron is smaller than the experimental value [16].

4.3 The diquark is coupled to the first two generations

In this subsection, we present an example to show that one can address simultaneously the issue of DCS $D^0 \rightarrow K^+ \pi^-$ decays, the contributions to $\Delta I = 1/2$ transitions and the direct CP violation in kaon sector without large FCNC. For simplicity, we assume the following 2×2 matrices for h^R and h^L

$$h^R = \begin{pmatrix} 1 & \lambda^4 \\ \lambda^2 & \lambda^2 \end{pmatrix}, \quad h^L = \lambda \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}, \quad (28)$$

i.e. the diquark is coupled to the first two generation quark fields. Note that the matrix elements of h_L and h_R merely have the meaning of order of magnitude, therefore, it should be understood, for instance, $h_{11}^L \sim O(\lambda)$, and $\lambda = 0.22$ is the Wolfenstein parameter. So our analysis is at qualitative level.

From (28) $h_{11}^{L*} h_{22}^L \sim h_{11}^{R*} h_{22}^R \sim O(\lambda^2)$, and $h_{11}^{R*} h_{22}^L \sim O(\lambda)$, so induced by the diquark, one can obtain the DCS $D^0 \rightarrow K^+ \pi^-$ decays amplitude which can be compared with the SM contribution, as shown in eq. (2).

Now we check the $D^0 - \overline{D}^0$ mixing generated by the diquark exchange. The most relevant box diagrams are $\chi - \chi$ -box and $\chi - W$ -box, which have been drawn in Figure 1. Here,

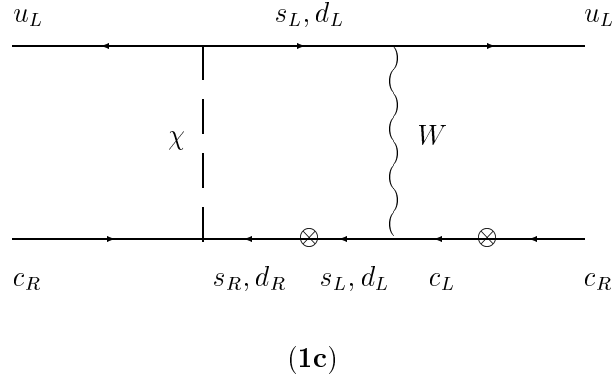
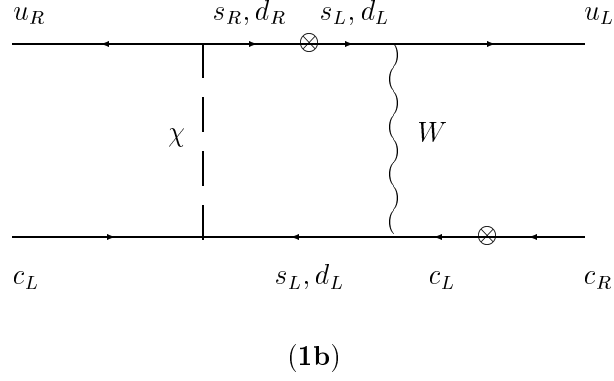
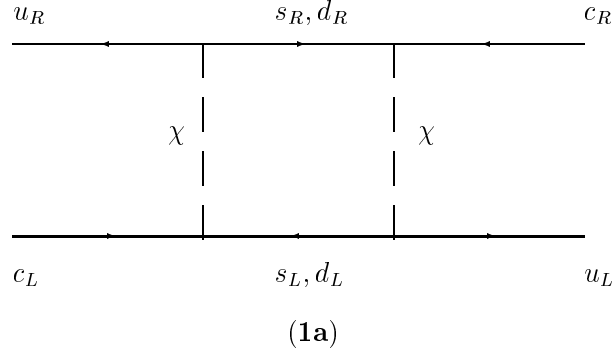


Figure 1: The box diagrams contributing to $D^0 - \overline{D^0}$ mixing. The \otimes denotes the chirality flip on the internal and external lines.

we only consider the contributions induced by the LR chiral structure, and the calculation is straightforward. From Fig. (1a), one can get

$$\xi(h_{22}^{L*}h_{12}^L + h_{21}^{L*}h_{11}^L) \cdot (h_{21}^{R*}h_{11}^R + h_{12}^{R*}h_{22}^R) (\overline{u_R}c_L)(\overline{u_L}c_R), \quad (29)$$

where

$$\xi = \frac{g_L^2 g_R^2}{16\pi^2 m_\chi^2} \sim 10^{-10} \text{ GeV}^{-2} \quad (30)$$

for the same values of g_L , g_R , and m_χ used in eq. (19). Likewise, the contributions of Fig. (1b) and Fig. (1c) are respectively

$$\frac{G_F}{\sqrt{2}} \frac{g_L g_R m_c}{4\pi^2 m_\chi^2} (V_{cd}h_{21}^L + V_{cs}h_{22}^L) \cdot (m_d h_{11}^{R*} V_{ud}^* + m_s h_{12}^{R*} V_{us}^*) (\overline{u_R}c_L)(\overline{u_L}c_R), \quad (31)$$

and

$$\frac{G_F}{\sqrt{2}} \frac{g_L g_R m_c}{4\pi^2 m_\chi^2} (V_{ud}^* h_{11}^{L*} + V_{us}^* h_{12}^{L*}) \cdot (m_d h_{21}^R V_{cd} + m_s h_{22}^R V_{cs}) (\overline{u_L}c_R)(\overline{u_L}c_R). \quad (32)$$

Experimentally, as shown in eq. (10), $x \leq 0.03$, and the SM predicts $x_{\text{SM}} \sim 10^{-3}$. Using eq. (28), we can get that all the above box diagrams lead to $x_\chi \sim 10^{-3} - 10^{-2}$, not larger than the experimental value.

From eq. (28) $h_{11}^{R*}h_{12}^L \sim O(\lambda)$ and thus the amplitudes of non-leptonic $\Delta I = 1/2$ transitions of kaon decays could be $10^{-2}G_F$. In order to check the problem of FCNC, similar box diagrams, which are shown in Figure 2, have been calculated. Fig. (2a), Fig. (2b) and Fig. (2c) will give respectively the following contributions

$$\xi(h_{11}^{L*}h_{12}^L + h_{21}^{L*}h_{22}^L) \cdot (h_{12}^{R*}h_{11}^R + h_{12}^{R*}h_{22}^R) (\overline{d_L}s_R)(\overline{d_R}s_L), \quad (33)$$

$$\frac{G_F}{\sqrt{2}} \frac{g_L g_R m_s}{4\pi^2 m_\chi^2} (V_{us}h_{12}^L + V_{cs}h_{22}^L) \cdot (m_c h_{21}^{R*} V_{cd}^* + m_u h_{11}^{R*} V_{ud}^*) (\overline{d_L}s_R)(\overline{d_R}s_L), \quad (34)$$

and

$$\frac{G_F}{\sqrt{2}} \frac{g_L g_R m_s}{4\pi^2 m_\chi^2} (V_{ud}^* h_{11}^{L*} + V_{cd}^* h_{21}^{L*}) \cdot (m_u h_{12}^R V_{us} + m_c h_{22}^R V_{cs}) (\overline{d_L}s_R)(\overline{d_L}s_R). \quad (35)$$

It is easy to find that all the above contributions are not larger than the SM prediction of the $K^0 - \overline{K}^0$ mixing.

Another FCNC problem could be Z^0 penguin diagram contribution to the decay $K_L \rightarrow \mu\overline{\mu}$. It will generate the following effective hamiltonian

$$\frac{g_L g_R \alpha_{\text{EM}} m_c m_\mu}{4\pi m_\chi^2 m_W^2 \sin^2 \theta_W} (h_{22}^{L*}h_{21}^R + h_{21}^{L*}h_{22}^R) \overline{d}\gamma_5 s \overline{\mu}\gamma_5 \mu, \quad (36)$$

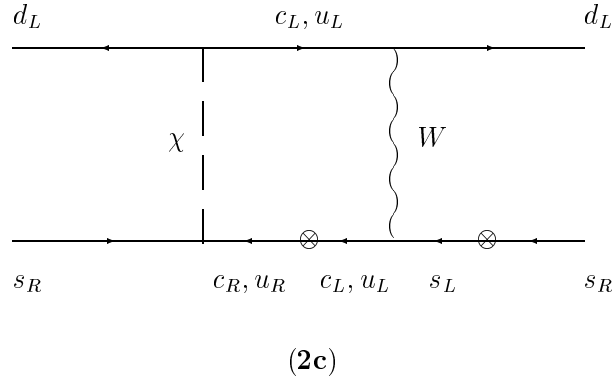
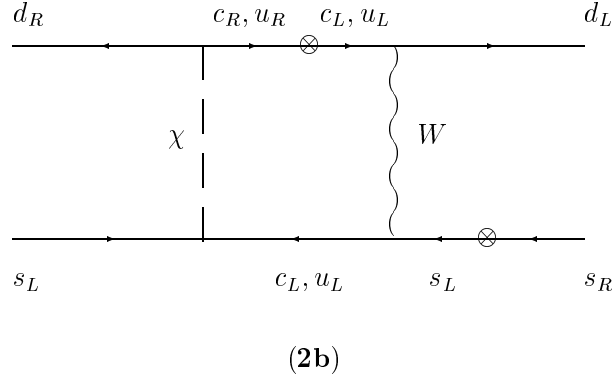
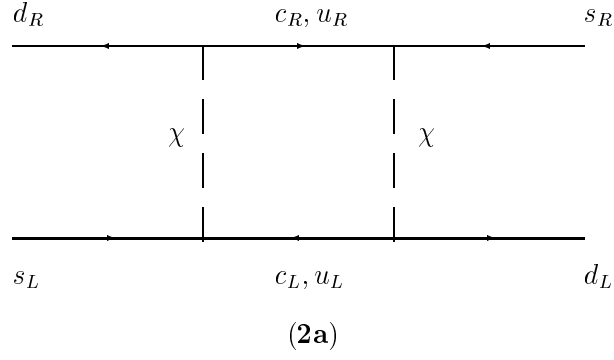


Figure 2: The box diagrams contributing to $K^0 - \overline{K}^0$ mixing. The \otimes denotes the chirality flip on the internal and external lines.

which has to be compared with the SM prediction $\sim \lambda^2(10^{-12}\text{GeV}^{-2})\bar{d}\gamma_5 s \bar{\mu}\gamma_5 \mu$ and thus substantially smaller.

Furthermore, if we put a small electroweak phase $\varphi \sim 10^{-2}$ in h_{12}^L , $\Im m(h_{12}^L h_{11}^{R*}) \sim \lambda \sin \varphi \sim 10^{-3}$ and eq. (27) will hold. Also as pointed out in the previous subsection, no large electric dipole moment of the neutron will be induced.

It has been shown that, in the simple realization (28) with only one diquark, we get the enhancement of the amplitudes of DCS $D^0 \rightarrow K^+ \pi^-$ decays and non-leptonic $\Delta I = 1/2$ transitions of kaon decays up to $10^{-2} G_F$ without any dangerous FCNC. Phenomenologically we could also make $h_{12}^L \sim O(1)$ and not $O(\lambda)$ as in eq. (28), which means that a larger contribution to $\Delta I = 1/2$ kaon decays would be possible. However, we do not want h^L in (28) to depart severely from a symmetric structure, but a larger enhancement could be still achieved from the hadronic matrix element.

5 Conclusions

In this paper, we have constructed a class of models motivated by diquark exchange, which can generate large contributions to the DCS $D^0 \rightarrow K^+ \pi^-$ decays without affecting $D^0 - \bar{D}^0$ mixing. Our conclusion somewhat disagrees with the statement in Ref. [4] that the New Physics can only affect significantly the mixing but not the decay. A large direct CP asymmetry in $D^\pm \rightarrow K_S \pi^\pm$ is possible in our model, which may be regarded as the signal to look for New Physics scenarios.

All the chiral structures including LL , RR , and LR can lead to the enhancement of the DCS decays in the charm sector, however, only LR structure is useful in kaon sector when we impose the constraints by avoiding the large FCNC. It is particularly interesting that this LR structure can generate novel density \times density operators, which can induce the pure $\Delta I = 1/2$ transitions and new direct CP violation. To our knowledge, the role of these operators in non-leptonic kaon decays is discussed for the first time in the present paper.

ACKNOWLEDGMENTS

G.D. wishes to thank Shelly Glashow for drawing his attention on diquark contributions in weak interactions, Riccardo Barbieri and Gino Isidori for very illuminating discussions, and the support of the ‘‘Bruno Rossi’’ INFN-MIT exchange program.

References

- [1] G. Buchalla, hep-ph/0103166.
- [2] I.I. Bigi, hep-ph/0104008.
- [3] S. Bergmann, Y. Grossman, Z. Ligeti, Y. Nir, and A. Petrov, Phys. Lett. **B** 486 (2000) 418.
- [4] S. Bergmann and Y. Nir, J. High Energy Phys. **09** (1999) 031.
- [5] J.M. Link *et al.* (FOCUS collaboration), Phys. Lett. B **485** (2000) 62; Phys. Rev. Lett. **86** (2001) 2955.
- [6] R. Godang *et al.* (CLEO collaboration), Phys. Rev. Lett. **84** (2000) 5038.
- [7] A.J. Buras, hep-ph/0101336; G. Buchalla, A.J. Buras, and M.E. Lautenbacher, Rev. Mod. Phys. **68** (1996) 1125; A. Pich, hep-ph/9806303; G. D'Ambrosio and G. Isidori, Int. J. Mod. Phys. A **13** (1998) 1; G. Isidori, hep-ph/0011017.
- [8] P.H. Frampton, S.L. Glashow, and T. Yoshikawa, hep-ph/0103022.
- [9] L. Wolfenstein, Phys. Rev. Lett. **75** (1995) 2460; T.E. Browder and S. Pakvasa, Phys. Lett. B **383** (1996) 475; A.F. Falk, Y. Nir, and A.A. Petrov, J. High Energy Phys. **9912** (1999) 019.
- [10] F. Zwirner, Int. J. Mod. Phys. A **3** (1988) 49.
- [11] B.A. Campbell, J. Ellis, K. Enqvist, M.K. Gaillard, and D.V. Nanopoulos, Int. J. Mod. Phys. A **2** (1987) 831.
- [12] J.L. Hewett and T.G. Rizzo, Phys. Rep. **183** (1989) 193.
- [13] H.P. Nilles, Phys. Rep. **110** (1984) 1; S.P. Martin, hep-ph/9709356.
- [14] M.B. Voloshin, hep-ph/0011099.
- [15] I. Bigi and H. Yamamoto, Phys. Lett. B **349** (1995) 363.
- [16] M.V. Romalis, W.G. Griffith, and E.N. Fortson, Phys. Rev. Lett. **86** (2001) 2505.